DESCRIPTION

OFDM RECEPTION APPARATUS AND OFDM RECEPTION METHOD

5   TECHNICAL FIELD

[0001]   The present invention relates to an apparatus and a method of receiving a signal which is modulated using an Orthogonal Frequency Division Multiplexing (OFDM) technique and is transmitted.

10   BACKGROUND ART

[0002]   OFDM is used as a transmission technique for digital terrestrial broadcasting in Europe and Japan, wireless LAN, and the like.   The OFDM technique is a method of performing modulation/demodulation by assigning data to a plurality of carriers orthogonal to each other.   An Inverse Fast Fourier Transform (IFFT) process is performed in a

15   transmitter, while a Fast Fourier Transform (FFT) process is performed in a receiver. Any modulation method can be applied to each carrier, including QPSK (Quaternary Phase Shift Keying), QAM (Quadrature Amplitude Modulation), and the like.

[0003]   Generally, in apparatuses receiving digital terrestrial broadcasting, frequency characteristics of a transmission channel (channel response) is estimated based on a pilot

20   signal inserted in a received OFDM signal, and the estimated channel response is used to perform waveform equalization.

[0004]   An exemplary technique concerning such channel response estimation and waveform equalization is described in Patent Document 1 below.   In Patent Document 1, a received pilot signal is separated from an OFDM signal which has been converted into a

25   frequency domain signal by an FFT circuit, and is divided by a known pilot signal to obtain the channel response of a carrier which transmits the received pilot signal.   Further, the channel response is smoothed in a time direction by a symbol filter, i.e., interpolation is

performed between symbols, and thereafter, interpolation is performed between carriers by an interpolation circuit, to obtain a channel response H(l, kd). A received data signal Y(l, kd) is divided by the channel response H(l, kd) to obtain equalized data X(l, kd).

[0005]   When a channel response is estimated by performing interpolation between symbols and between carriers using a filter in this manner, noise overlaps the estimated channel response. A power of the noise (noise power) increases with an increase in pass band width of a filter for interpolation between carriers, and decreases with a decrease in the pass band width. Therefore, in order to remove an influence of the noise to improve the precision of channel estimation, it is effective to narrow the pass band width of the filter.

[0006]   According to the transmission standards for digital terrestrial television broadcasting in Europe and Japan, any one of Tu/4, Tu/8, Tu/16, and Tu/32 (Tu: effective symbol duration) is adopted as a guard interval so as to transmit an OFDM signal. In a receiver, a delay time of multipath interference which can be removed is determined, depending on the guard interval. For example, when the guard interval is Tu/4, a main wave can be received while removing an influence of a delayed wave having a delay time of Tu/4 or less. Therefore, in order to remove the multipath influence to improve channel estimation precision, it is effective to widen the pass band width of the filter.

[0007]   Therefore, in the interpolation circuit described in Patent Document 1, a guard interval is determined from a received OFDM signal, and based on the determined guard interval, a coefficient of a filter which is used to perform interpolation between carriers (hereinafter referred to as a "carrier filter") in the interpolation circuit is controlled so that pass band widths of the filter are switched. Specifically, when the guard interval is long, the filter coefficient is set so as to widen the pass band width. When the guard interval is short, the filter coefficient is set so as to narrow the pass band width.

[0008]   As described above, in the interpolation circuit, the band widths of the filter for interpolation are switched so as to fit the guard interval, thereby suppressing and reducing

a noise component overlapping the estimated channel response.

Patent Document 1: Japanese Patent Unexamined Publication No. 11-163822

DISCLOSURE OF THE INVENTION

5   PROBLEMS TO BE SOLVED BY THE INVENTION

[0009]   In the case where the pass band width of a carrier filter is controlled based on a guard interval as described above, a carrier filter having a widest pass band width when a transmission channel is estimated, is used in order to receive an OFDM signal whose guard interval is Tu/4.   In this case, the effect of suppressing and reducing a noise component of

10   a carrier filter becomes minimum, so that the channel estimation precision is significantly deteriorated.

[0010]   For example, in the case where an OFDM signal whose guard interval is Tu/8 is received, if a delayed wave whose delay time exceeds Tu/8 is present, the delay time exceeds the pass band width (Tu/8) of the filter, so that a channel response cannot be

15   estimated.

[0011]   When the estimation precision of the channel response thus obtained is low, demodulation cannot be correctly performed, so that OFDM signal reception performance is significantly deteriorated.

[0012]   An object of the present invention is to improve channel estimation precision

20   when receiving an OFDM signal.

SOLUTION TO THE PROBLEMS

[0013]   The present invention is directed to an OFDM reception apparatus of receiving and demodulating an OFDM (Orthogonal Frequency Division Multiplexing) signal which

25   transmits a pilot signal whose amplitude and phase are known.   The apparatus calculates a channel response before interpolation based on the received OFDM signal, performs interpolation with respect to the before-interpolation channel response using a plurality of

filters having different characteristics from each other to obtain a plurality of interpolated channel responses, and uses one which provides a high-quality demodulated signal among the plurality of interpolated channel responses to obtain a demodulated signal.

[0014]   Specifically, the present invention is directed to an OFDM reception apparatus for receiving and demodulating an OFDM signal which transmits a pilot signal whose amplitude and phase are known.   The apparatus comprises a channel estimation section for calculating a channel response before interpolation by performing computation between a frequency-domain OFDM signal obtained by Fourier-transforming the received OFDM signal and the pilot signal, performing interpolation with respect to the before-interpolation channel response using a plurality of filters having different characteristics from each other, and outputting a plurality of interpolated channel responses based on respective results of the interpolation obtained by the plurality of filters, an equalization section for performing waveform equalization with respect to the frequency-domain OFDM signal based on the plurality of interpolated channel responses, and outputting a plurality of demodulated signals based on respective results of the waveform equalization corresponding to the plurality of interpolated channel responses, a determination section for determining one having best quality from the plurality of demodulated signals, and outputting a result of the determination, and a selection section for selecting and outputting one of the plurality of demodulated signals in accordance with the determination result.

[0015]   According to the present invention, among channel responses obtained from a plurality of filters having different characteristics, a channel response which provides a high-quality demodulated signal can be known.   Thus, it is possible to improve channel estimation precision, thereby obtaining a demodulated signal having high quality.

EFFECT OF THE INVENTION

[0016]   According to the present invention, when an OFDM signal is received, even if noise interference or multipath interference is present in the received signal, channel

estimation precision or the quality of a demodulated signal can be improved, depending on an interference situation, without depending on a guard interval. As a result, it is possible to improve reception performance of an OFDM reception apparatus or the like.

5   BRIEF DESCRIPTION OF THE DRAWINGS

[0017]   [FIG. 1] FIG. 1 is a block diagram illustrating an exemplary example of an OFDM reception apparatus according to an embodiment of the present invention.

[FIG. 2] FIG. 2 is a block diagram illustrating an exemplary structure of an OFDM demodulation section according to a first embodiment of the present invention.

10   [FIG. 3] FIG. 3 is a diagram illustrating an exemplary arrangement format of a pilot signal in an OFDM signal received by the OFDM reception apparatus of FIG. 1.

[FIG. 4] FIG. 4 is a diagram illustrating positions at which channel responses interpolated in a symbol direction by the symbol interpolating section of FIG. 2 are obtained.

15   [FIG. 5] FIG. 5 is a diagram illustrating positions at which channel responses interpolated in a carrier direction by a wide-band filter and a narrow-band filter of FIG. 2 are obtained.

[FIG. 6] FIGS. 6(a) and 6(b) are diagrams illustrating a channel response obtained by a wide-band filter and a channel response obtained by a narrow-band filter, respectively,

20   under environment of Gaussian noise interference.

[FIG. 7] FIGS. 7(a) and 7(b) are diagrams illustrating a channel response obtained by a wide-band filter and a channel response obtained by a narrow-band filter, respectively, under environment of multipath interference.

[FIG. 8] FIG. 8 is a block diagram illustrating an exemplary structure of a quality

25   detecting section of FIG. 1.

[FIG. 9] FIG. 9 is a block diagram illustrating an exemplary structure of an OFDM demodulation section according to a second embodiment of the present invention.

[FIG. 10] FIG. 10 is a block diagram illustrating a structure of an OFDM demodulation section according to a variation of the second embodiment of the present invention.

[FIG. 11] FIG. 11 is a block diagram illustrating an exemplary structure of an OFDM demodulation section according to a third embodiment of the present invention.

[FIG. 12] FIG. 12 is a block diagram illustrating an exemplary structure of an OFDM demodulation section according to a fourth embodiment of the present invention.

[FIG. 13] FIG. 13 is a schematic diagram illustrating an example of a magnitude |HP| of a channel response with respect to a pilot carrier of a received OFDM signal when noise overlaps the OFDM signal.

[FIG. 14] FIG. 14 is a diagram illustrating a level of an impulse response obtained in an IFFT section of FIG. 12.

[FIG. 15] FIGS. 15(a) and 15(b) are diagrams illustrating impulse responses before and after removal of noise components, respectively.

[FIG. 16] FIG. 16 is a diagram illustrating a channel response obtained in an FFT section of FIG. 12.

[FIG. 17] FIG. 17 is a diagram illustrating a channel response HP' obtained in a noise removing section of FIG. 12.

[FIG. 18] FIG. 18 is a block diagram illustrating a structure of an OFDM demodulation section according to a variation of the fourth embodiment of the present invention.

DESCRIPTION OF THE REFERENCE CHARACTERS

16, 17, 17A, 17B, 416, 417, 516, 517	delay section
19, 319, 419, 519	selection section
20, 220, 320	channel estimation section
40, 42	symbol interpolating section

43, 51, 351	wide-band filter
44, 52, 352	narrow-band filter
50, 53, 54, 350, 453	carrier interpolating section
60, 360, 460	equalization section
70, 670	noise removing section
71, 671	IFFT section
72, 672	zero replacement section
73, 673	FFT section
74, 674	end portion replacement section
80, 380, 480	determination section
81, 82, 82A, 82B	quality detecting section
83, 383	comparison section
463	division section
583	difference detecting section

BEST MODE FOR CARRYING OUT THE INVENTION

[0019]   Hereinafter, embodiments of the present invention will be described in detail with reference to the accompanying drawings.

[0020]   FIG. 1 is a block diagram illustrating an exemplary example of an OFDM reception apparatus according to an embodiment of the present invention.   The OFDM reception apparatus **100** of FIG. 1 comprises a tuner **3**, an OFDM demodulation section **4**, an error correction section **5**, a source decoding section **6**, and an output section **7**.

[0021]   In FIG. 1, a signal received by an antenna **1** is supplied to the tuner **3** in the OFDM reception apparatus **100**.   The tuner **3** subjects the received signal thus supplied to extraction of an OFDM signal containing a desired service, frequency conversion from an RF (Radio Frequency) band to an IF (Intermediate Frequency) band, gain adjustment, and the like, and outputs results of these processes to the OFDM demodulation section **4**.

The OFDM demodulation section **4** demodulates a signal **DI** supplied from the tuner section **3** based on frequency characteristics of a transmission channel (channel response), and output a demodulation result **DO** to the error correction section **5**.

[0022]   The error correction section **5** restores transmitted digital data from the demodulation result **DO** of the OFDM demodulation section **4**, corrects a transmission error caused by, for example, external perturbation applied to the transmission channel, using Viterbi decoding, Reed-Solomon decoding, or the like, and outputs the result to the source decoding section **6**. The source decoding section **6** separates the output of the error correction section **5** into data, such as video, audio, and the like, and thereafter, subjects the separated data to a data decompression process, and outputs the result to the output section **7**. Of the outputs of the source decoding section **6**, the output section **7** displays video information on a CRT (Cathode Ray Tube) or the like, outputs audio information via a loudspeaker, and the like, to provide a desired service to the user. Also, the output section **7** can output an output of the source decoding section to an external apparatus.

[0023]   Hereinafter, various examples of the OFDM demodulation section will be described.

[0024]   (First embodiment)

FIG. **2** is a block diagram illustrating an exemplary structure of an OFDM demodulation section **4** according to a first embodiment of the present invention. The OFDM demodulation section **4** comprises a quadrature demodulation section **11**, an FFT section **12**, a channel estimation section **20**, an equalization section **60**, a determination section **80**, delay sections **16** and **17**, and a selection section **19**.

[0025]   The quadrature demodulation section **11** performs quadrature demodulation to frequency-convert an output of the tuner **3** of FIG. **1** from a signal in an IF band into a signal in a base band, and outputs the result to the FFT section **12**. In this case, the output of the tuner **3**, which is a real signal, is converted into a complex signal consisting of an I

(In Phase) axis component and a Q (Quadrature Phase) axis component.

[0026]   The FFT section 12 converts an output of the quadrature demodulation section 11 from an OFDM signal in a time domain into an OFDM signal in a frequency domain, and outputs the resultant frequency-domain OFDM signal Y to the channel estimation section 20 and the equalization section 60. The frequency-domain OFDM signal Y output from the FFT section 12 indicates a phase and an amplitude of each carrier of an OFDM signal, and specifically, is represented by a complex signal having an I-axis direction level and a Q-axis direction level independently.

[0027]   The channel estimation section 20 employs a plurality of filters having different characteristics from each other for interpolation so as to estimate a plurality of frequency characteristics of a transmission channel (channel responses) through which a received OFDM signal is transmitted, and comprises a channel response calculating section 30, a symbol interpolating section 42, and a carrier interpolating section 50.

[0028]   The channel response calculating section 30 has a pilot signal extracting section 31, a division section 32, and a pilot signal generating section 33. The carrier interpolating section 50 has a wide-band filter 51 and a narrow-band filter 52 as carrier interpolating filters. The equalization section 60 comprises division sections 61 and 62. The determination section 80 comprises quality detecting sections 81 and 82 and a comparison section 83.

[0029]   An operation of the thus-constructed OFDM demodulation section 4 according to the first embodiment of the present invention will be described in detail.

[0030]   FIG. 3 is a diagram illustrating an exemplary arrangement format of a pilot signal in an OFDM signal received by the OFDM reception apparatus of FIG. 1. Specifically, FIG. 3 illustrates the arrangement format of a pilot signal for the digital terrestrial broadcasting system (DVB-T) in Europe, the digital terrestrial broadcasting system (ISDB-T) in Japan, and the like.

[0031]   In FIG. 3, the horizontal axis (frequency axis) k indicates a carrier index, and

the vertical axis (time axis) l indicates a symbol index. A closed circle indicates a pilot signal (SP (Scattered Pilot)), and an open circle indicates a data signal (D) containing control information and additional information. As used herein, the control information is TPS (Transmission Parameter Signaling) in DVB-T or TMCC (Transmission Multiplexing

5   Configuration Control) in ISDB-T, and the additional information is AC (Auxiliary Channel) in ISDB-T.

[0032]   In FIG. 3, a pilot signal indicated with a closed circle is provided every 12 carriers in each symbol, and is shifted by 3 carriers every symbol. The pilot signal is modulated based on a pseudo-random binary sequence, and an amplitude and a phase

10   thereof are determined only by the index k of a provided carrier, without depending on the index l of a symbol.

[0033]   The pilot signal extracting section 31 extracts a pilot signal from a frequency-domain OFDM signal supplied from the FFT section 2, and outputs the pilot signal to the division section 32. The pilot signal generating section 33 generates a predetermined

15   pilot signal (SP signal in ISDB-T and DVB-T) whose amplitude and phase are known and which corresponds to the pilot signal supplied from the pilot signal extracting section 31 to the division section 32, and outputs the predetermined pilot signal to the division section 32.

[0034]   The division section 32 divides the pilot signal supplied from the pilot signal

20   extracting section 31 by the pilot signal supplied from the pilot signal generating section 33 to calculate frequency characteristics of a transmission channel for a carrier transmitting the pilot signal (hereinafter referred to as a pilot carrier), i.e., a channel response **HP**, and outputs the channel response **HP** to the symbol interpolating section 42. The channel response **HP** is obtained as a channel response before interpolation with respect to a

25   position at which a pilot signal SP is inserted in FIG. 3.

[0035]   The symbol interpolating section 42 subjects the channel response **HP** supplied from the division section 32 to symbol-direction (time axis-direction) filtering (band

limitation) to perform interpolation between symbols, and outputs a resultant channel response HS to the wide-band filter 51 and the narrow-band filter 52.

[0036]   FIG. 4 is a diagram illustrating positions at which channel responses interpolated in the symbol direction by the symbol interpolating section 42 of FIG. 2 are

5   obtained.   As illustrated in FIG. 4, the interpolated channel response HS is obtained at positions indicated by symbol CT.

[0037]   The wide-band filter 51 and the narrow-band filter 52 of the carrier interpolating section 50 have different characteristics from each other.   The wide-band filter 51 and the narrow-band filter 52 each subject the channel response HS supplied from

10   the symbol interpolating section 42 to carrier-direction (frequency axis-direction) filtering (band limitation) to perform interpolation between carriers.   The wide-band filter 51 outputs a resultant channel response HCW to the division section 61, and the narrow-band filter 52 outputs a resultant channel response HCN to the division section 62.

[0038]   FIG. 5 is a diagram illustrating positions at which channel responses

15   interpolated in the carrier direction by the wide-band filter 51 and the narrow-band filter 52 of FIG. 2 are obtained.   As illustrated in FIG. 5, the interpolated channel responses HCW and HCN are both obtained at positions indicated by symbol CF.

[0039]   The wide-band filter 51 and the narrow-band filter 52 are each composed of an FIR filter.   Note that the wide-band filter 51 and the narrow-band filter 52 have different

20   characteristics (i..e., pass bands) from each other, and in the first embodiment, it is assumed that the wide-band filter 51 has a pass band width of Tu/4 and the narrow-band filter 52 has a pass band width of Tu/8.

[0040]   FIGS. 6(a) and 6(b) are diagrams illustrating a channel response obtained by the wide-band filter 51 and a channel response obtained by the narrow-band filter 52,

25   respectively, under environment of Gaussian noise (hereinafter simply referred to as noise) interference.   In FIGS. 6(a) and 6(b), the vertical axis indicates a signal level (signal power) and the horizontal axis indicates time, and channel responses and noise which pass

through the wide-band filter 51 and the narrow-band filter 52 are converted into time-axis responses, which are illustrated.

[0041]   As illustrated in FIG. 6, a channel response has a shape having a peak, while noise overlapping the channel response is distributed evenly over the time axis. The

5   amount of noise passing through the narrow-band filter 52 is smaller than the amount of noise passing through the wide-band filter 51. Therefore, when an OFDM signal is received under environment in which noise interference is present, the narrow-band filter 52 obtains a higher level of channel estimation precision than that which is obtained by the wide-band filter 51.

10   [0042]   FIGS. 7(a) and 7(b) are diagrams illustrating a channel response obtained by the wide-band filter 51 and a channel response obtained by the narrow-band filter 52, respectively, under environment of multipath noise interference. In FIGS. 7(a) and 7(b), the vertical axis indicates a signal level and the horizontal axis indicates time, and channel responses which pass through the wide-band filter 51 and the narrow-band filter 52 are

15   converted into time-axis responses, which are illustrated.

[0043]   As illustrated in FIG. 7, when a delay time of a delayed wave with respect to a main wave exceeds the pass band width Tu/8 of the narrow-band filter 52, channel responses of the main wave and the delayed wave can both pass through the wide-band filter 51, but are interrupted by the narrow-band filter 52 and cannot pass therethrough.

20   Therefore, when an OFDM signal is received under environment of multipath interference in which a delayed wave having a long delay time exceeding the pass band width of a filter occurs, the wide-band filter 51 obtains a higher level of channel estimation precision than that which is obtained by the narrow-band filter 52.

[0044]   As described above, a difference in estimation precision may occur between the

25   channel responses HCW and HCN obtained by the wide-band filter 51 and the narrow-band filter 52, respectively, due to an interference factor, such as noise or multipath.

[0045]   The division section 61 divides the frequency-domain OFDM signal Y supplied

from the FFT section **12** by the channel response **HCW**, and outputs a resultant demodulated signal **XCW** to the delay section **16** and the quality detecting section **81**. The division section **62** divides the frequency-domain OFDM signal **Y** supplied from the FFT section **12** by the channel response **HCN**, and outputs a resultant demodulated signal **XCN** to the delay section **17** and the quality detecting section **82**. In other words, the division sections **61** and **62** compensate for waveform distortion which is caused due to multipath occurring in a transmission channel, by performing waveform equalization with respect to the frequency-domain OFDM signal **Y**.

[0046]   Here, the two channel responses **HCW** and **HCN** obtained in the carrier interpolating section **50** have different estimation precisions, depending on the situation of interference (noise, multipath), and therefore, the demodulated signals **XCW** and **XCN** obtained in the division sections **61** and **62** based on these channel responses have different quality levels, depending on the interference situation.

[0047]   The determination section **80** determines which of the demodulated signals **XCW** and **XCN** supplied from the division sections **61** and **62**, respectively, has a higher level of quality (better quality). The determination section **80** will be described. The quality detecting section **81** detects a quality value **QCW** of the demodulated signal **XCW**, and outputs the detection result to the comparison section **83**. The quality detecting section **82** detects a quality value **QCN** of the demodulated signal **XCN**, and outputs the detection result to the comparison section **83**. The comparison section **83** compares the quality value **QCW** and the quality value **QCN** to determine one of them which has a higher level of quality, and outputs the determination result to the selection section **19**.

[0048]   FIG. **8** is a block diagram illustrating an exemplary structure of the quality detecting section **81** of FIG. **1**. As illustrated in FIG. **8**, the quality detecting section **81** comprises a hard decision section **86**, a signal point-to-signal point distance calculating section **87**, and an average calculating section **88**. The quality detecting section **82** is assumed to have a structure similar to that of the quality detecting section **81**.

[0049]   The hard decision section **86** determines an ideal signal point which has a closest distance from a signal point on an I-Q plane of a carrier for the demodulated signal **XCW**, and outputs the ideal signal point as an ideal signal to the signal point-to-signal point distance calculating section **87**.   The signal point-to-signal point distance calculating section **87** calculates a signal point-to-signal point distance for each carrier based on the ideal signal output from the hard decision section **86**, and the demodulated signal **XCW**.

[0050]   Specifically, the signal point-to-signal point distance calculating section **87** calculates a square of a difference value between I-axis components and a square of a difference value between Q-axis components with respect to the ideal signal point on the I-Q plane indicated by the ideal signal and a signal point on the I-Q plane indicated by a demodulated signal, and calculates and outputs a sum of them as a signal point-to-signal point distance to the average calculating section **88**.

[0051]   The average calculating section **88** calculates an average value of signal point-to-signal point distances obtained over a plurality of carriers by the signal point-to-signal point distance calculating section **87**.   A period of time for which the average value is calculated may extend within one symbol or over a plurality of symbols.   The longer the calculation period, the higher the detection precision of the quality of a demodulated signal. Conversely, if the calculation period is decreased, a time required to obtain the determination result in the determination section **80** decreases, so that the hardware amount of delayers in the delay sections **16** and **17** can be reduced.

[0052]   With the thus-constructed determination section **80**, the signal quality values **QCW** and **QCN** can be respectively calculated from the two demodulated signals **XCW** and **XCN** which have different quality levels, depending on an interference situation, and based on a result of comparison of the calculated quality values **QCW** and **QCN**, a demodulated signal having a higher level of quality can be determined.

[0053]   The delay sections **16** and **17** delay the demodulated signals **XCW** and **XCN**, respectively, and output them to the selection section **19**.   The selection section **19** selects

one of the demodulated signals **XCW** and **XCN** which has better quality in accordance with the determination result output from the determination section **80**, and outputs the selection result as a demodulated signal **DO** to the error correction section **5**.

[0054]   Here, the delay sections **16** and **17** delay the demodulated signals **XCW** and **XCN**, respectively, by a time required for detection, comparison, and determination of a quality value in the determination section **80**, for example.   As a result, a difference is removed between timing of inputting the demodulated signals **XCW** and **XCN** to the selection section **19** and timing of inputting the determination result of these demodulated signals in the determination section **80** to the selection section **19**.   Therefore, even when the estimation precision situations of the two channel responses **HCW** and **HCN** output from the carrier interpolating section **50** are changed due to a change in the interference situation or the like, the OFDM demodulation section **4** can follow the change quickly and outputs an appropriate demodulated signal **DO**.

[0055]   Note that the delay sections **16** and **17** may not be provided.   In this case, it is possible to reduce circuit cost required for the delay sections **16** and **17**.

[0056]   Although, in the first embodiment of the present invention, the carrier interpolating section **50** is assumed to have two filters, the number of filters may be three or more.   Also in such a case, waveform equalization may be performed with respect to a channel response obtained for each filter, and a demodulated signal having a highest level of quality may be selected from the resultant demodulated signals.   Therefore, the quality precision of a demodulated signal can be more flexibly selected, depending on an interference situation, thereby making it possible to improve reception performance of the OFDM reception apparatus.

[0057]   Also in the first embodiment of the present invention, the carrier interpolating section **50** is assumed to comprise a plurality of filters having different pass bands (pass band widths).   Instead, the carrier interpolating section **50** may comprise a plurality of filters having the same pass band width, but pass bands shifted from each other (center

positions of the pass bands are shifted from each other). For example, two filters having a pass band width of Tu/4 may be provided, one of the two filters having a pass band ranging from 0 to Tu/4 (the center position is Tu/2), and the other having a pass band ranging from -Tu/8 to +Tu/8 (the center position is 0). In this case, the quality precision of a

5   demodulated signal can be more flexibly selected even in a multipath interference situation, which has various delay times, thereby making it possible to improve reception performance of the OFDM reception apparatus. Alternatively, a plurality of filters having different pass band widths and pass bands shifted from each other (the center positions of the pass bands are shifted from each other) may be provided.

10   [0058]   Thus, the OFDM reception apparatus of the first embodiment of the present invention performs waveform equalization based on a channel response obtained for each of a plurality of filters having different characteristics (pass bands) when demodulating a received OFDM signal, and determines and selects one of a plurality of resultant demodulated signals which has best quality. Therefore, it is possible to improve the

15   reception performance of the OFDM reception apparatus even in a situation in which any of the Gaussian noise interference and the multipath interference can occur, without depending on a guard interval.

[0059]   (Second embodiment)

FIG. 9 is a block diagram illustrating an exemplary structure of an OFDM

20   demodulation section 204 according to a second embodiment of the present invention. In the second embodiment, the OFDM demodulation section 204 is employed instead of the OFDM demodulation section 4, in the OFDM reception apparatus of FIG. 1. The OFDM demodulation section 204 of FIG. 9 is different from the OFDM demodulation section 4 of FIG. 2 in that a channel estimation section 220 is provided instead of the channel

25   estimation section 20. The other components are similar to those which have been described with reference to FIG. 2 and are referenced with the same reference numerals, and will not be explained.

[0060]   The channel estimation section **220** has a channel response calculating section **30**, a symbol interpolating section **40**, and carrier interpolating sections **53** and **54**. The channel response calculating section **30** is similar to that which has been described with respect to FIG. **2**.

[0061]   The symbol interpolating section **40** comprises a wide-band filter **43** and a narrow-band filter **44** which have different characteristics from each other. These filters have different pass bands from each other. The wide-band filter **43** and the narrow-band filter **44** subject a channel response **HP** from a division section **32** to symbol-direction filtering to perform interpolation between symbols. The wide-band filter **43** outputs a resultant channel response **HSW** to the carrier interpolating section **53**, and the narrow-band filter **44** outputs a resultant channel response **HSN** to the carrier interpolating section **54**. The interpolated channel responses **HSW** and **HSN** are obtained at the positions indicated with symbol CT in FIG. **4**.

[0062]   Here, the wide-band filter **43** and the narrow-band filter **44** are each composed of an FIR filter. In the second embodiment of the present invention, the wide-band filter **43** is assumed to serve as a first-order interpolation filter and the narrow-band filter **44** is assumed to serve as a zeroth-order interpolation filter.

[0063]   More specifically, the wide-band filter **43** performs linear interpolation with timing of symbols based on a channel response **HP** corresponding to a pilot signal obtained every 4 symbols. When a temporal variation in channel response is significant during mobile reception or the like (fading interference or the like), a relatively high level of channel estimation precision can be secured, though the effect of suppressing noise is relatively low, so that the estimation precision may be deteriorated during noise interference or the like.

[0064]   On the other hand, the narrow-band filter **44** performs interpolation using an average value of channel responses **HP** corresponding to pilot signals inserted into symbols before and after a received symbol, so that the pass band width is narrower than

that of the wide-band filter **43**.   Therefore, when a temporal variation in channel response is large during fading interference or the like, channel estimation precision is deteriorated, however, since the effect of suppressing noise is relatively high, a relatively high level of estimation precision can be secured during noise interference.

5   [0065]   As described above, a difference in estimation precision may occur in the channel responses **HSW** and **HSN** obtained in the wide-band filter **43** and the narrow-band filter **44**, due to an interference factor, such as noise or fading.

[0066]   The carrier interpolating section **53** performs interpolation between carriers with respect to the channel response **HSW**, and outputs the resultant interpolated channel

10   response **HCW** to the division section **61**.   The carrier interpolating section **54** performs interpolation between carriers with respect to the channel response **HSN**, and outputs the resultant interpolated channel response **HCN** to the division section **62**.

[0067]   The two channel responses **HCW** and **HCN** obtained in the channel estimation section **220** have different estimation precisions, depending on the situation of interference

15   (noise, fading).   Therefore, the demodulated signals **XCW** and **XCN** obtained based on these channel responses in the equalization section **60** also have different quality levels, depending on the interference situation.

[0068]   As described above, also in the second embodiment of the present invention, the quality value of each signal can be calculated from the two demodulated signals **XCW**

20   and **XCN** which have different quality levels, depending on the interference situation, and based on the calculated quality values, a demodulated signal having a higher level of quality can be selected.

[0069]   Although, in the second embodiment of the present invention, the symbol interpolating section **40** is assumed to have two filters, the number of filters may be three

25   or more.   Also in such a case, waveform equalization may be performed with respect to a channel response obtained for each filter, and a demodulated signal having a highest level of quality may be selected from the resultant demodulated signals.   Therefore, the quality

precision of a demodulated signal can be more flexibly selected, depending on an interference situation, thereby making it possible to improve the reception performance of the OFDM reception apparatus.

[0070]   FIG. 10 is a block diagram illustrating a structure of an OFDM demodulation section according to a variation of the second embodiment of the present invention.   The OFDM demodulation section 304 of FIG. 10 comprises a channel estimation section 320, an equalization section 360, a determination section 380, a the delay section 17A, and a selection section 319 instead of the channel estimation section 220, the equalization section 60, the determination section 80, the delay section 17, and the selection section 19 of the OFDM demodulation section 204 of FIG. 9, and further, a the delay section 17B.

[0071]   The channel estimation section 320 comprises a carrier interpolating section 350 instead of the carrier interpolating section 54 in the channel estimation section 220.   The carrier interpolating section 350 has a wide-band filter 351 and a narrow-band filter 352 as carrier interpolating filters.   The wide-band filter 351 and the narrow-band filter 352 are similar to the wide-band filter 51 and the narrow-band filter 52 of FIG. 2, respectively. The equalization section 360 comprises division sections 61, 62A, and 62B.   The determination section 380 comprises quality detecting sections 81, 82A, and 82B, and a comparator 383.

[0072]   The wide-band filter 351 and the narrow-band filter 352 subject the channel response HSN supplied from the symbol interpolating section 42 to carrier-direction filtering to perform interpolation between carriers.   The wide-band filter 351 outputs a resultant channel response HCW1 to the division section 62A, and the narrow-band filter 352 outputs a resultant channel response HCN1 to the division section 62B.

[0073]   The division section 62A divides the frequency-domain OFDM signal Y supplied from the FFT section 12 by the channel response HCW1, and outputs a resultant demodulated signal XCN1 to the delay section 17A and the quality detecting section 82A. The division section 62B divides the frequency-domain OFDM signal Y supplied from the

FFT section **12** by the channel response **HCN1**, and outputs a resultant demodulated signal **XCN2** to the delay section **17B** and the quality detecting section **82B**.

[0074]   The quality detecting section **82A** detects a quality value **QCN1** of the demodulated signal **XCN1**, and outputs the detection result to the comparator **383**.   The quality detecting section **82B** detects a quality value **QCN2** of the demodulated signal **XCN2**, and outputs the detection result to the comparator **383**.   The comparator **383** compares the quality values **QCW**, **QCN1**, and **QCN2** to select a value having a highest level of quality, and outputs the determination result to the selection section **319**.

[0075]   The delay sections **17A** and **17B** are similar to the delay section **16**, and delay the demodulated signals **XCN1** and **XCN2**, respectively, and output the delayed signals to the selection section **319**.   The selection section **319** selects one of the demodulated signals **XCW**, **XCN1**, and **XCN2** which has best quality in accordance with the determination result output from the determination section **380**, and outputs the selection result as a demodulated signal **DO** to the error correction section **5**.

[0076]   According to the OFDM demodulation section **304** of FIG. **10**, one can be selected from a larger number of demodulated signals, depending on a situation, such as noise interference, multipath interference, fading interference, or the like, thereby making it possible to further improve reception performance.   For example, it is assumed that the carrier interpolating sections **53** and **54** of the OFDM demodulation section **204** of FIG. **9** and the carrier interpolating sections **53** of the OFDM demodulation section **304** of FIG. **10** each have a filter having the same characteristics as those of the wide-band filter **351**.   In this case, when only noise interference is present in a received signal, the OFDM demodulation section **304** can obtain the channel response **HCN1** which has a smaller amount of overlapping noise than that of any of the other channel responses **HCW**, **HCN**, and **HCW1**.   Therefore, reception performance can be improved under environment of noise interference, as compared to the OFDM demodulation section **204**.

[0077]   Note that the OFDM demodulation section of FIG. **10** may comprise the carrier

interpolating section **350** instead of the carrier interpolating section **53**. Specifically, four channel responses may be calculated, waveform equalization may be performed based on each channel response to obtain four demodulated signals, and one which has a highest level of quality may be selected from the four demodulated signals.

[0078]   (Third embodiment)

FIG. **11** is a block diagram illustrating an exemplary structure of an OFDM demodulation section **404** according to a third embodiment of the present invention. In the third embodiment, the OFDM demodulation section **404** is used instead of the OFDM demodulation section **4** in the OFDM reception apparatus of FIG. **1**.

[0079]   The OFDM demodulation section **404** of FIG. **11** comprises a quadrature demodulation section **11**, an FFT section **12**, a channel response calculating section **30**, a symbol interpolating section **40**, an equalization section **460**, a determination section **480**, delay sections **416** and **417**, a selection section **419**, a carrier interpolating section **453**, and a division section **463**. The same components as those described with reference to FIGS. **2** and **9** are indicated with the same reference numerals and will not be explained.

[0080]   The equalization section **460** comprises division sections **461** and **462**. The division section **461** divides the frequency-domain OFDM signal **Y** supplied from the FFT section **12** by the channel response **HSW** output from the wide-band filter **43**, and outputs a resultant demodulated signal **XSW** to a quality detecting section **481**. The division section **462** divides the frequency-domain OFDM signal **Y** supplied from the FFT section **12** by the channel response **HSN** output from the narrow-band filter **44**, and outputs a resultant demodulated signal **XSN** to a quality detecting section **482**.

[0081]   The two channel responses **HSW** and **HSN** obtained in the symbol interpolating section **40** have different estimation precisions, depending on an interference (noise, fading) situation. Therefore, the demodulated signals **XSW** and **XSN** obtained in the respective division sections **461** and **462** based on the channel responses also have different quality levels, depending on the interference situation. Note that the channel

responses **HSW** and **HSN** obtained in the symbol interpolating section **40** are obtained at the positions indicated by symbol CT of carriers on which a pilot signal is transmitted (FIG. 4), and the demodulated signals **XSW** and **XSN** obtained in the equalization section **460** are also obtained at the same positions as these positions.

[0082]   The determination section **480** comprises the quality detecting sections **481** and **482**, and a comparison section **483**.   These components have a similar configuration to that of the determination section **80** of FIG. **2**.   The determination section **480** determines one of the demodulated signals **XSW** and **XSN** which has a higher level of quality (better quality).   The quality detecting section **481** detects a quality value **QSW** of the demodulated signal **XSW**, and outputs the detection result to the comparison section **483**. The quality detecting section **482** detects a quality value **QSN** of the demodulated signal **XSN**, and outputs the detection result to the comparison section **483**.   The comparison section **483** determines one of the quality value **QSW** and the quality value **QSN** which has a higher level of quality, and outputs the determination result to the selection section **419**.

[0083]   According to the thus-constructed determination section **480**, the quality values **QSW** and **QSN** of a signal are calculated from the two demodulated signals **XSW** and **XSN** which have different quality levels, depending on an interference situation, and based on a result of comparison of the calculated quality values **QSW** and **QSN**, a channel response having a higher level of estimation precision can be determined.

[0084]   The delay sections **416** and **417** delay the channel responses **HSW** and **HSN**, respectively, and output the results to the selection section **419**.   The selection section **419** selects one of the channel response **HSW** and **HSN** which has better quality in accordance with the determination result output from the determination section **480**, and outputs the selected channel response **HS** to the carrier interpolating section **453**.

[0085]   Here, the delay sections **416** and **417** delay the channel response **HSW** and **HSN** by a time required for processes in the equalization section **460** and the determination

section **480**, respectively, for example. As a result, a difference is removed between timing of inputting the channel responses **HSW** and **HSN** to the selection section **419** and timing of inputting the determination result of the determination section **480** with respect to these channel responses to the selection section **419**. Therefore, even when a change

5 occurs in the situation of the estimation precision of the two channel responses **HSW** and **HSN** output from the symbol interpolating section **40**, the OFDM demodulation section **404** can follow the change quickly.

[0086]   Note that the delay sections **416** and **417** may not be provided. In this case, circuit cost required for the delay sections **416** and **417** can be reduced.

10 [0087]   The carrier interpolating section **453** subjects the channel response **HS** selected in the selection section **419** to carrier-direction filtering, thereby performing interpolation between carriers. The carrier interpolating section **453** outputs an interpolated channel response **HC** to the division section **463**. As illustrated in FIG. **5**, the interpolated channel response **HC** is obtained at the positions indicated with symbol CF.

15 [0088]   The division section **463** divides the frequency-domain OFDM signal **Y** supplied from the FFT section **12** by the channel response **HC**, and outputs a resultant demodulated signal **DO**. In other words, the division section **463** compensates for waveform distortion occurring in a transmission channel due to multipath by performing waveform equalization with respect to the frequency-domain OFDM signal **Y**.

20 [0089]   According to the third embodiment of the present invention, an appropriate one is selected from channel responses before carrier interpolation, thereby making it possible to suppress the computation amount of the determination section.

[0090]   (Fourth embodiment)

FIG. **12** is a block diagram illustrating an exemplary structure of an OFDM

25 demodulation section **504** according to a fourth embodiment of the present invention. The OFDM demodulation section **50** comprises a quadrature demodulation section **11**, an FFT section **12**, a channel response calculating section **30**, a symbol interpolating section

42, a carrier interpolating section 50, a noise removing section 70, a difference detecting section 583, delay sections 516 and 517, a selection section 519, and a division section 461. The quadrature demodulation section 11, the FFT section 12, the channel response calculating section 30, the symbol interpolating section 42, and the carrier interpolating section 50 are similar to those which have been described with reference to FIG. 2 and will not be explained in detail.

[0091]   The noise removing section 70 subjects a channel response **HP** to IFFT to calculate an impulse response, and based on the impulse response, removes a noise component overlapping the channel response **HP**, and outputs the noise-removed channel response **HP'** to the symbol interpolating section 42.   The noise removing section 70 comprises an IFFT section 71, a zero replacement section 72, an FFT section 73, and an end portion replacement section 74.

[0092]   FIG. 13 is a schematic diagram illustrating an example of a magnitude |**HP**| of a channel response with respect to a pilot carrier of a received OFDM signal when noise overlaps the OFDM signal.   The magnitude |**HP**| of a channel response is ideally constant, however, in FIG. 13, distortion occurs therein over an entire band.

[0093]   The IFFT section 71 performs IFFT with respect to the channel response **HP** obtained in the channel response calculating section 30 for each symbol to convert the channel response **HP** from a frequency-domain signal to a time-domain signal, and outputs the resultant time-domain signal, i.e., an impulse response, to the zero replacement section 72.   The impulse response is obtained in the form of a complex signal (vector) having a component in each of the I- and Q-axis directions.

[0094]   FIG. 14 is a diagram illustrating a level (a square of a magnitude) of an impulse response obtained in the IFFT section 71 of FIG. 12.   As can be seen from FIG. 14, the channel response level has a local peak, however, noise components are distributed over an entire region on the time axis.   The zero replacement section 72 removes noise components from the impulse response.

[0095]   FIGS. 15(a) and 15(b) are diagrams illustrating impulse responses before and after removal of noise components, respectively.   As illustrated in FIG. 15(a), the zero replacement section 72 sets a threshold to be a predetermined level.   The zero replacement section 72 calculates a sum of a sqare value of an I-axis component and a square value of an Q-axis component of an impulse response output from the IFFT section 71 as a power of the impulse response, compares the impulse response power with the set threshold, replaces an impulse response having a power smaller than the threshold with "0 vector", and outputs an impulse response having a power no smaller than the threshold, as it is, to the FFT section 73.   The zero replacement section 72 outputs the replaced impulse response as illustrated in FIG. 15(b).

[0096]   The FFT section 73 subjects the noise component-removed impulse response to FFT to convert it back into a frequency-domain signal, and outputs the resultant signal to the end portion replacement section 74.   FIG. 16 is a diagram illustrating a channel response obtained in the FFT section 73 of FIG. 12.   As illustrated in FIG. 16, an influence of truncation of data may deteriorate characteristics of a band at its both end portions.   The end portion replacement section 74 is provided so as to bypass the above-described noise removing process for the purpose of avoding the deterioration of the characteristics of the both band end portions.

[0097]   The end portion replacement section 74 outputs a channel response within a predetermined frequency band including a middle portion of a band, as it is, among the channel responses output from the FFT section 73, and replaces channel responses in the vicinity of bands other than the frequency band, i.e., the band end portions having a significant deterioration in characteristics (a low band portion and a high band portion), with a channel response HP before removal of a noise component.   The end portion replacement section 74 outputs the resultant channel response HP' to the symbol interpolating section 42.   In this case, noise is removed from the channel response HP' of the middle portion of a band which has not been subjected to replacement, while noise is

not removed from the channel response **HP'** of the band end portions which has been subjected to replacement.

[0098]   FIG. 17 is a diagram illustrating the channel response **HP'** obtained in the noise removing section **70** of FIG. **12**.   As illustrated in FIG. **17**, an influence of noise is removed from the middle portion of a band, while noise is not removed and remains at both the band end portions.

[0099]   Note that, in the noise removing section **70**, in order to reduce the influence of truncation, the channel response **HP** may be multiplied by an appropriate window function before IFFT, or alternatively, a channel response obtained in the FFT section **73** may be divided by the window function.

[0100]   The symbol interpolating section **42** subjects the noise-removed channel response **HP'** to intersymbol filtering to perform symbol-direction interpolation, and outputs a symbol-interpolated channel response **HS** to the wide-band filter **51** and the narrow-band filter **52** of the carrier interpolating section **50**.   The wide-band filter **51** and the narrow-band filter **52** calculate channel responses **HCW** and **HCN**, respectively.   The wide-band filter **51** outputs the resultant channel response **HCW** to the delay section **516** and the difference detecting section **583**, and the narrow-band filter **52** outputs the resultant channel response **HCN** to the delay section **517** and the difference detecting section **583**.

[0101]   In the channel response **HS** obtained by symbol-direction interpolation of an output of the noise removing section **70**, noise is removed from the middle portion of the band.   Therefore, in the channel responses **HCW** and **HCN** obtained in the wide-band filter **51** and the narrow-band filter **52**, respectively, under environment of noise interference, there is substantially no difference between the middle portions thereof due to an influence of noise.

[0102]   On the other hand, under environment in which multipath interference is present, particularly when a delay time exceeds the pass band width of the narrow-band filter **52**, a difference occurs between the channel responses **HCW** and **HCN** (FIGS. **7(a)**

and **7(b)**). In such a case, whereas the wide-band filter **51** obtains a correct channel response, the narrow-band filter **52** does not obtain a correct channel response. Therefore, a significant difference occurs between the channel responses **HCW** and the channel response **HCN** obtained in the wide-band filter **51** and the narrow-band filter **52**, respectively.

[0103] As has already been described, the wider the pass band width of a filter for carrier interpolation, the longer the delay time of a delayed wave which can be estimated. In this case, however, a larger amount of noise overlaps the estimated channel response.

[0104] Therefore, the difference detecting section **583** detects the presence or absence of a difference between the channel response **HCW** and the channel response **HCN** in the band middle portion (or a part thereof) (or that a value of the difference exceeds a predetermined range), and outputs the detection result to the selection section **519**.

[0105] In order to detect a difference in the difference detecting section **583**, a difference value between I-axis components and a difference value between Q-axis components may be calculated with respect to the channel response **HCW** and the channel response **HCN** of the band middle portion, a sum of squares of these difference values may be calculated as a difference power for each carrier, and it may be determined whether or not a highest value of the difference power exceeds a predetermined value. Alternatively, a magnitude of the difference power between the channel response **HCW** and the channel response **HCN** of the band middle portion may be accumulated over all carriers belonging to the band middle portion, and it may be determined whether or not a result of the accumulation exceeds a predetermined value. Note that, in the difference detecting section **583**, the difference detection may be performed in the whole or a part of the band middle portion.

[0106] The delay sections **516** and **517** delay the channel responses **HCW** and **HCN**, respectively, and output the results to the selection section **519**. The selection section **519** selects one of the channel responses **HCW** and **HCN** based on the detection result output

from the difference detecting section **583**, and outputs the selected channel response **HC** to the division section **461**.

[0107] Specifically, when there is not a difference between the channel response **HCW** and the channel response **HCN** of the band middle portion (or a value of the difference falls within a predetermined range), the channel response **HCN** obtained by the narrow-band filter **52** which has a high level of effect of suppressing noise is selected, and is output as the channel response **HC** for the entire band. As a result, a channel response in which the influence of noise is reduced at the both end portions can be obtained.

[0108] On the other hand, when there is a difference between the channel responses **HCW** and **HCN** of the band middle portion (or the value of the difference exceeds a predetermined range), the channel response **HCW** obtained by the wide-band filter **51** which has a high level of estimation precision in a multipath transmission channel is selected as a channel response at the band end portions, and is output as the channel response **HC** for the entire band. As a result, it is possible to obtain a channel response which has an improved level of estimation precision of a multipath transmission channel.

[0109] Here, for example, the delay sections **516** and **517** delay the channel responses **HCW** and **HCN**, respectively, by a time required for the process of the difference detecting section **583**. As a result, a difference is removed between timing of inputting the channel responses **HCW** and **HCN** to the selection section **519** and timing of inputting the detection result of the difference detecting section **583** with respect to these channel responses to the selection section **519**. Therefore, even when a change occurs in the situation of the estimation precision of the two channel responses **HCW** and **HCN** output from the carrier interpolating section **50**, the OFDM demodulation section **504** can follow the change quickly.

[0110] The division section **461** divides the frequency-domain OFDM signal **Y** by the channel response **HC** to perform waveform equalization with respect to the frequency-domain OFDM signal **Y**. Thereby, the division section **461** compensates for waveform

distortion occurring in a transmission channel due to multipath interference, and outputs a resultant demodulated signal **DO**.

[0111] The thus-obtained channel response **HC** for the entire band is obtained by appropriate selection from outputs of a plurality of filters used in channel estimation, under environment in which noise interference or multipath interference is present. Therefore, the estimation precision of the transmission channel is high, and by using the channel response to perform waveform equalization, reception performance can be improved. In addition, the selection from the outputs of a plurality of filters can be performed for each symbol, so that the ability to follow is considerably excellent under environment in which a channel response varies.

[0112] Note that the delay sections **516** and **517** may not be provided. In this case, circuit cost required for the delay sections **516** and **517** can be reduced.

[0113] In addition, the selection section **519** may select one of the channel responses **HCW** and **HCN** as a channel response for the entire band, when the selection is performed based on the detection result of a difference between the channel response **HCW** and the channel response **HCN** in the band middle portion. Alternatively, the channel response **HCW** may be invariably selected for the band middle portion, while one of the channel responses **HCW** and **HCN** may be selected only for the band end portions. As has already been described, the influence of noise is removed from the channel response of the band middle portion, and therefore, the channel response **HCW** can be invariably used for the band middle portion without a problem.

[0114] When the selection is performed only for the band end portions, any one of the channel responses may be selected only for one of the end portions, e.g., a high-band end portion. In this case, the hardware amount of delayers in the delay sections **516** and **517** can be reduced.

[0115] FIG. **18** is a block diagram illustrating a structure of an OFDM demodulation section **604** according to a variation of the fourth embodiment of the present invention.

The OFDM demodulation section **604** comprises a noise removing section **670** instead of the noise removing section **70** in the OFDM demodulation section **504** of FIG. **12** so that a noise removing process is performed after a symbol interpolation process.

[0116]   The symbol interpolating section **42** subjects the channel response **HP** obtained by the channel response calculating section **30** to intersymbol filtering to perform symbol-direction interpolation, and outputs the symbol-interpolated channel response to the noise removing section **670**.

[0117]   The noise removing section **670** comprises an IFFT section **671**, a zero replacement section**672**, an FFT section **673**, and an end portion replacement section **674**, which have substantially the same configuration as that of the noise removing section **70** of FIG. **12**. The noise removing section **670** removes a noise component overlapping a channel response output from the symbol interpolating section **42**, and outputs a noise-removed channel response **HS** to the wide-band filter **51** and the narrow-band filter **52**, as in the noise removing section **70**.

[0118]   Thus, when symbol-direction interpolation is performed before a noise removing process, noise can be removed from the band middle portion.

[0119]   Although, in the above-described embodiments of the present invention, the symbol interpolating section or the carrier interpolating section is assumed to have two filters having different characteristics, the number of filters may be three or more. Also in such a case, waveform equalization may be performed with respect to a channel response obtained for each filter, and a demodulated signal having a highest level of quality may be selected from the resultant demodulated signals. Therefore, the quality precision of a demodulated signal can be more flexibly selected, depending on an interference situation, thereby making it possible to improve the reception performance of the OFDM reception apparatus.

INDUSTRIAL APPLICABILITY

[0120] As described above, according to the present invention, channel estimation precision can be adaptively enhanced or the quality of a demodulated signal can be improved, without being affected by interference conditions of a transmission channel, such as Gaussian noise, multipath, or the like, and without depending on a guard interval.

5 Therefore, the present invention is useful as, for example, an OFDM reception apparatus of receicing an OFDM signal of digital broadcasting, wireless LAN, or the like.